COMPOSITIONAL CONSTRAINTS ON GIANT PLANET FORMATION: THE ROLE OF PROBES

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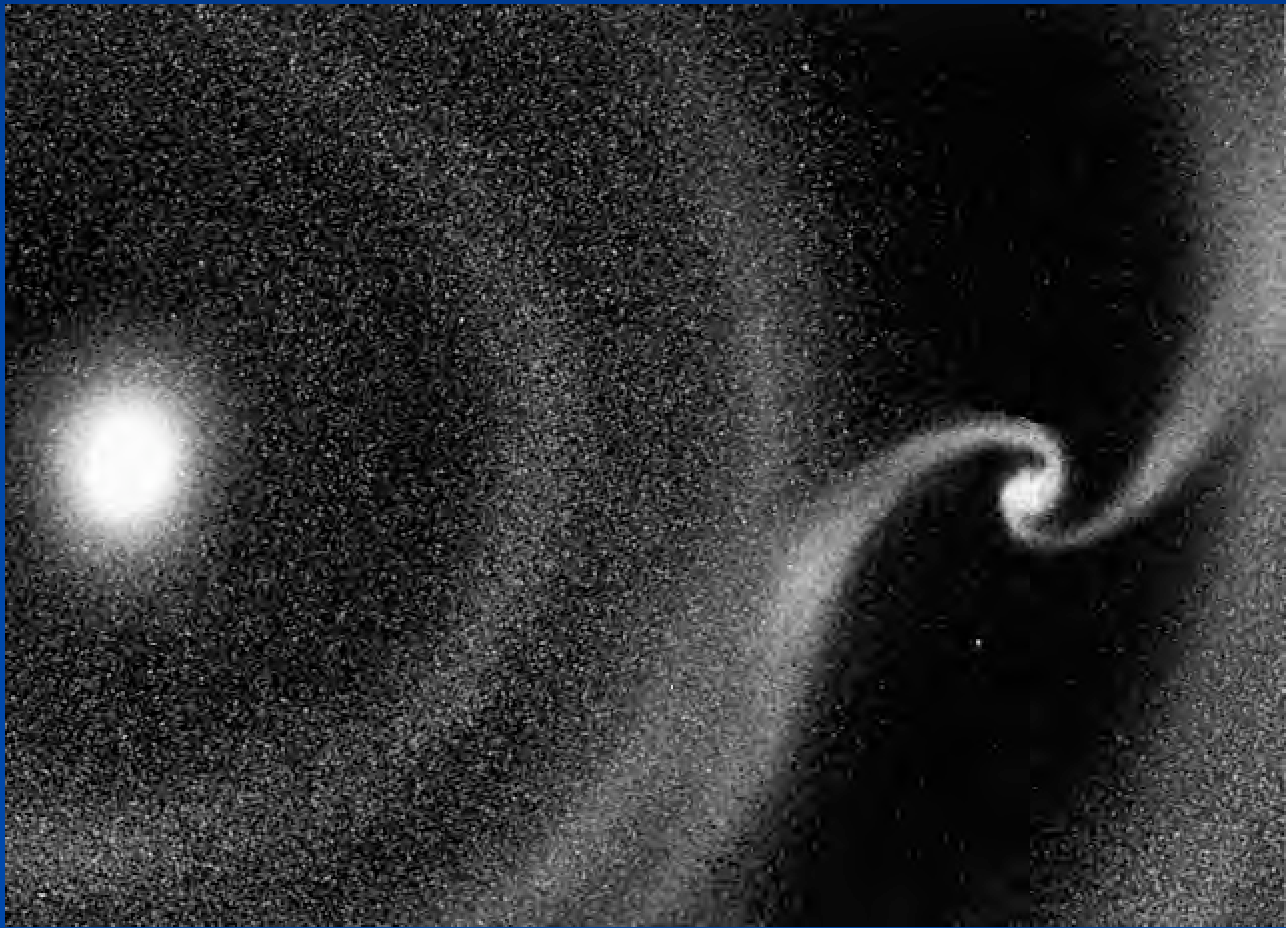
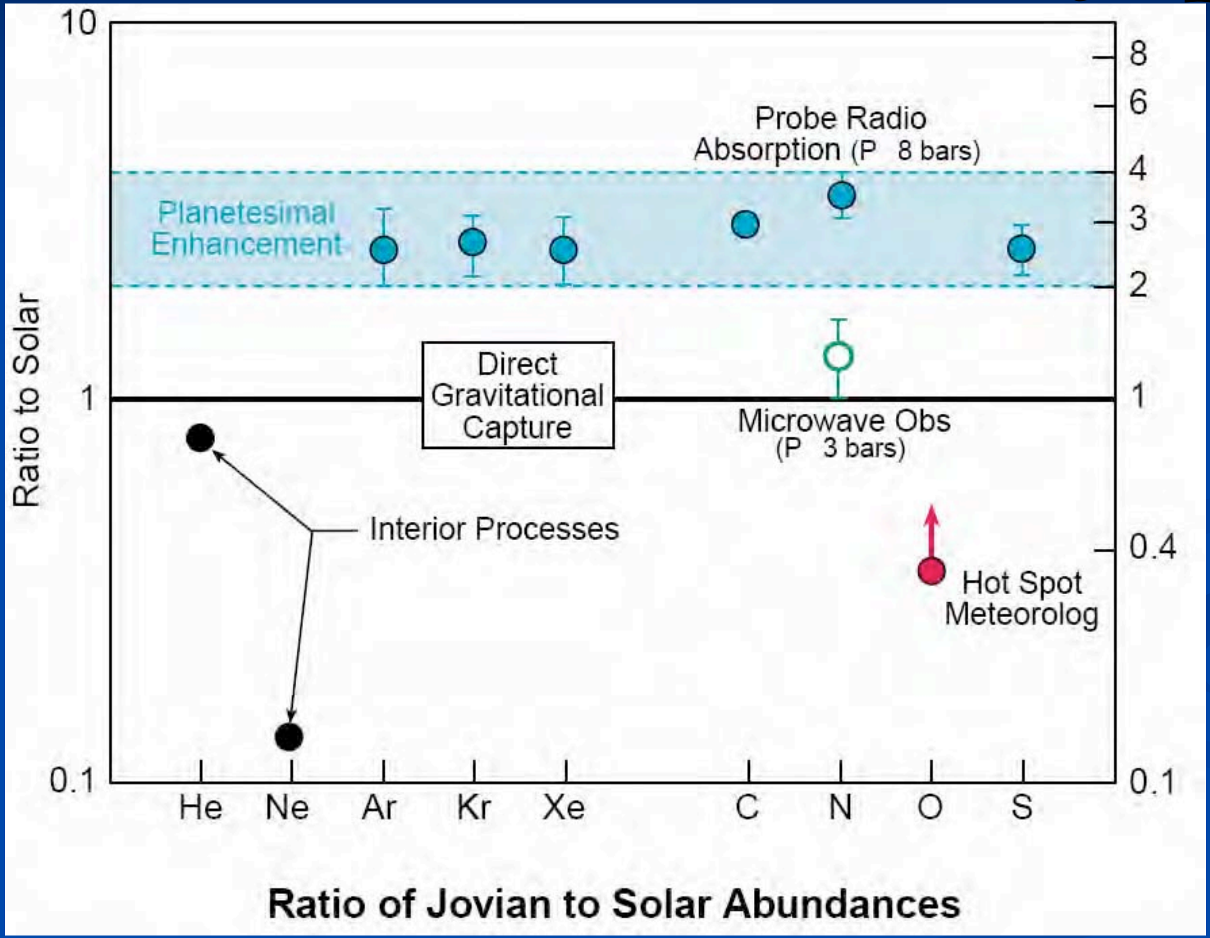
Present models of solar system formation are at an impasse



Galileo Probe Results on Jupiter



$Z_{\text{Jupiter}} \sim 3 \times Z_{\text{Sun}}$

Possible Solution:
Solar Composition Icy Planetesimals (SCIPs)

- All measured heavy elements present in solar abundance
- Implications:
  - Jupiter has 18 Me of heavy elements (fits models)
  - N was captured as N2 (fits isotopes: 15N/14N)
  - Planetesimals formed at low temp
    - Clathrate Hydrates, T<38 K
    - Amorphous Ice, T<20 K
  - Most abundant solid material in early solar system!

Major Puzzles - SCIPs

- Low Temperatures – Where and When?

- Timescales and Transport

- Remnants – Where are they?
  - **Oort Cloud?**
  - **KBOs?**
  - **?**

Composition

- Most fundamental investigation
- Evidence indicates core & atmosphere mixed
- Yields critical constraints on internal structure models
- Gives important clues to formation and nature of solar nebula
- Can then be applied to giant extra-solar planets studies

What Measurements are Needed

- Not necessary to include *all* present in planet's troposphere
- **Not essential to reach depths below the condensation points of water and ammonia.**
- Major progress will result from measurements of abundances and isotope ratios
  - all five noble gases,
  - abundances of methane
  - isotope ratios of hydrogen
  - carbon and nitrogen.

Composition Measurements

- Need *in situ* measurements from entry probes
- Is the *only* way to detect species such as noble gases and N2
- Such instruments enable determination of isotope ratios

He/H

- For Saturn/Jupiter: amount of helium dissolved in metallic hydrogen constrains models (internal structure and evolution)
- For Uranus and Neptune: (no metallic hydrogen) ratio should be starting value in solar nebula
- Comparison with present value in sun provides critical test of models for solar evolution

Ne/H

- How cold were planetesimals that produced the planet cores?
- To trap Ne, need planetesimals to form below 15 K.
- Otherwise Ne/H will be solar on Uranus and Neptune, as Ne should reach planet with H2 and He, as untrapped gas.
- On Saturn, expect Ne/H < Solar, as Ne dissolves in He raindrops separating out in interior.

Ar, Kr, Xe

- If trapped by freezing or adsorption (< 25 K): expect similar enrichment as CH4 (~7 x Saturn, 30-40 x Uranus/Neptune
- If trapped in clathrate hydrates, variety of different ratios could ensue, including hugely disproportionate enrichment of xenon on Neptune, for example.

CH4

- Earth remote sensing and s/c indicates enriched by factor of ~7 for Saturn and 30-40 x solar on Uranus and Neptune.
- Consistent with carbon trapped in the core converted to CH4 and mixed with the planets' envelopes.
- Uranus and Neptune uncertainties are still large, and to test the means by which the methane was formed, one must have a comparison with other gases, e.g., Ar, Kr, and Xe.

Trace Gases

- One of the features of a mass spectrometer is that it is not predisposed to analyze a certain suite of gases. Thus at each planet, we will be able to search for other trace constituents in addition to studying the gases we know or are quite sure are there

Isotopes : D/H and 12C/13C

- Cassini CIRS will measure at Saturn
- Needed for Uranus and Neptune.
- Do not expect 12C/13C to be different than sun, Earth, Venus, Mars, Jupiter.
- Constancy of ratio implies most carbon originated as solid material: organic compounds or grains
- Without a large volatile reservoir with which to exchange, isotopes fractionation was difficult.
- For D/H, look for signs of enriched value on Uranus and Neptune reflecting the mixing of hydrogen from water ice in cores with the hydrogen in the outer envelopes.

Isotopes: Noble Gases

- Expect to find isotope ratios identical to those in the sun and Jupiter, but there could be some surprises.
- Need to investigate the xenon isotopes, which are known to vary considerably in different sources around the solar system, for reasons not well understood.

14N/15N: Isotopes

- Key ratio for understanding the nature of planetesimals that formed the cores and enriched the envelopes of planets
- If planetesimals form at 25 K, then nitrogen trapped in N2
- Implies value ~2.3 ± 0.3 x 10-3 (Jupiter)
- Very different from Earth ~3.7 x 10^-3 presumably because our nitrogen reached us in form of NH3 or other nitrogen compounds
- Nitrogen isotopes thus provide excellent test for molecular form of original planetary N and hence the nature of the planetesimals
- **Note to measure isotopes, not necessary to probe beneath the condensation level of NH3**

Enrichment on Giant Planets

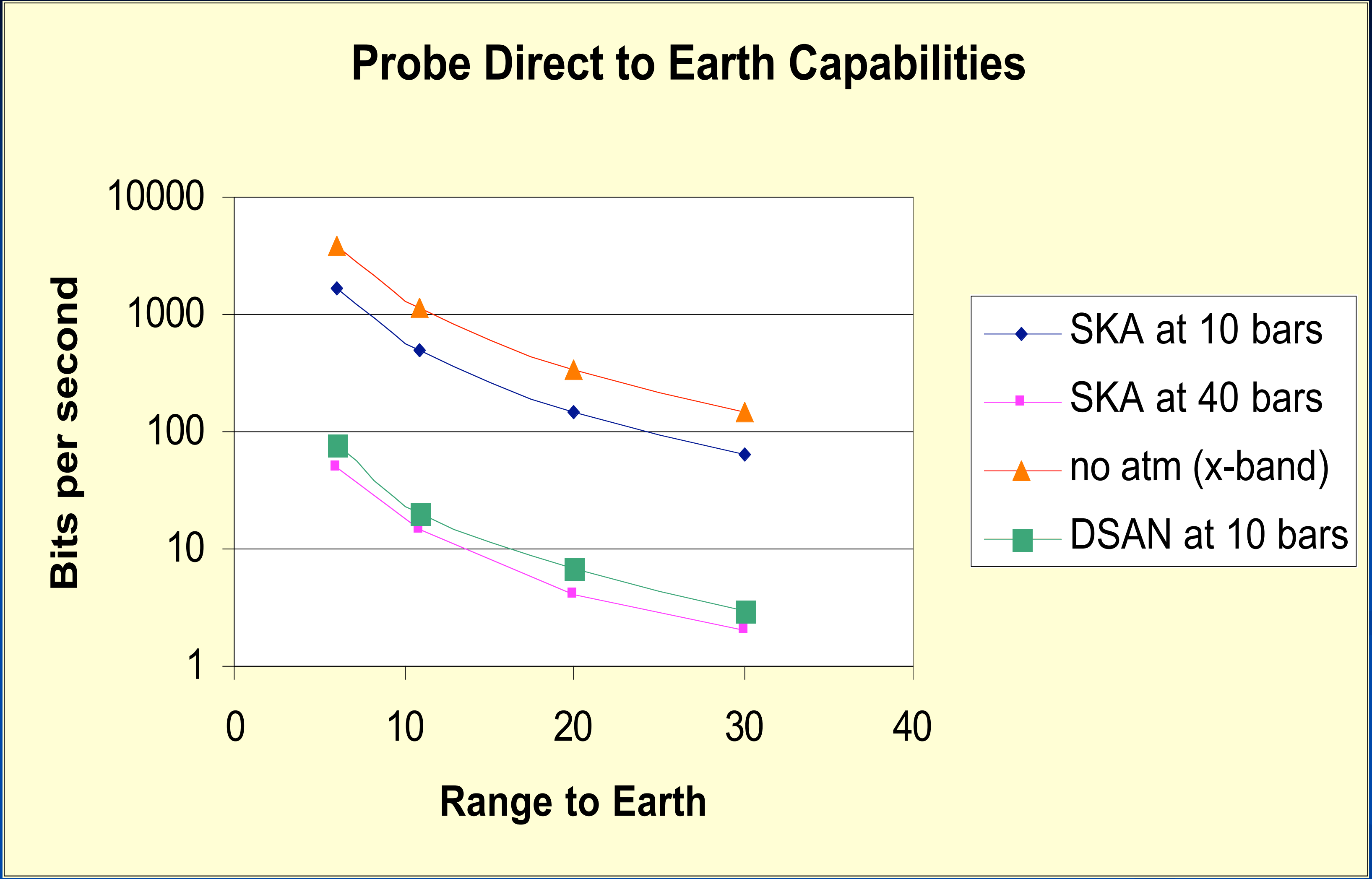
(Hersant et al. (2003)

	Jupiter		Saturn		Uranus/Neptune	
Ar	2.5	(5 bars)	1	(5 bars)	1	(5 bars)
Kr	2.7	(5 bars)	1	(5 bars)	1	(5 bars)
Xe	3.7	(5 bars)	17	(5 bars)	35-170	(>20 bars)
C	3	(5 bars)	2.5	(5 bars)	30-60	(5 bars)
N	3	(5 bars)	2.0[1]	(5 bars)	3-5[1]	(>200)
S	2.6[2]	(5 bars)	12.5[2]	(5 bars)	10-50*	(>40)
O	10.5	(>20 bars)	5.8	(25 bars)	90-175	(>200)

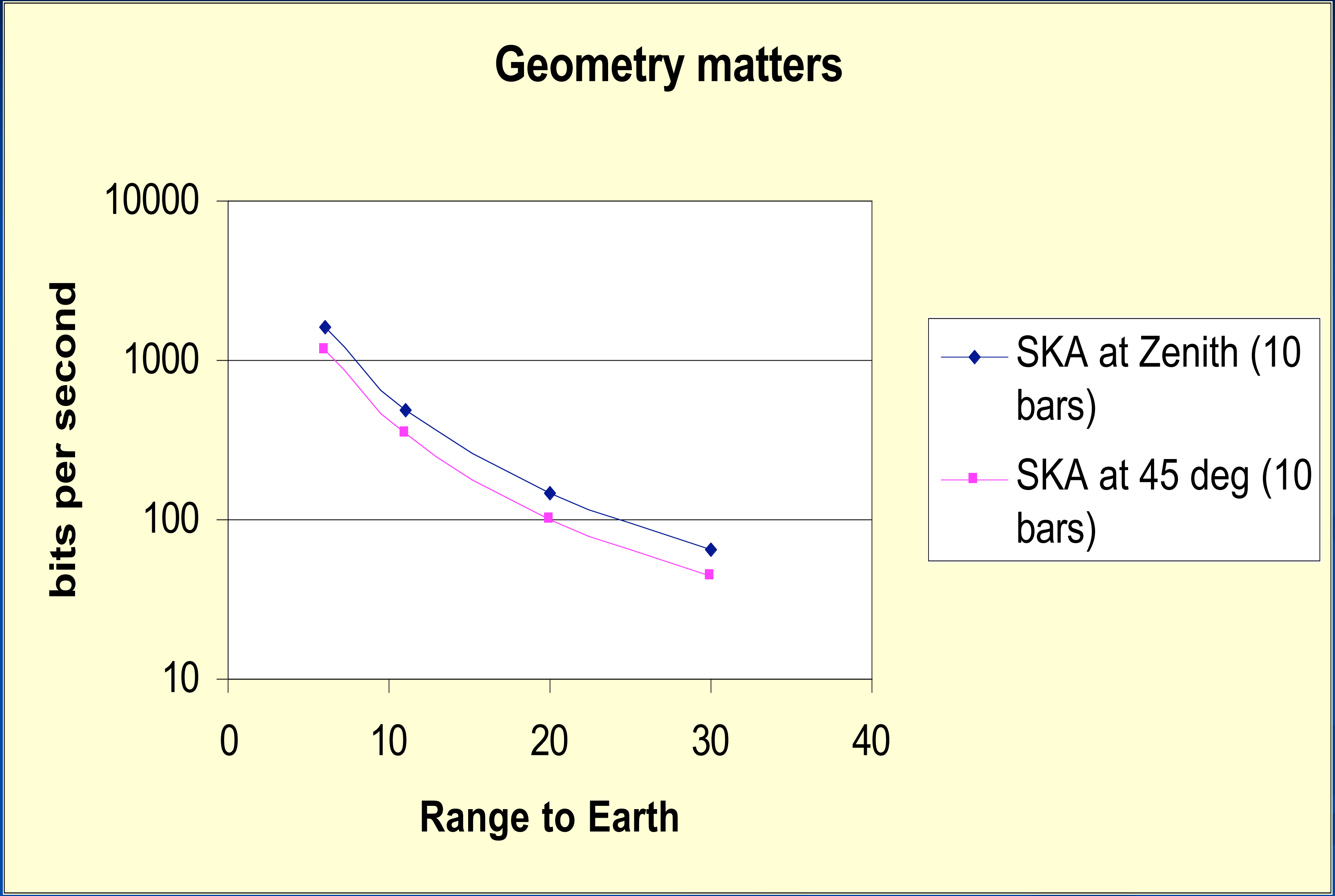
[1] assumes N trapped as NH3, [2] assumes H2S/H2=0.57 x Solar in Nebula

Depth Requirement is Critical

- Saturn, Uranus and Neptune probes would return important results at <5-10 bars
- Water for Saturn, Uranus and Neptune requires >200 bars: represents major communication challenge and significant cost
- Useful data rates at 5-10 bars at all outer planets possible with direct communications
- Direct-communications relieves the requirement for a relay spacecraft typically many times the cost of the probe itself.



Calculations assume attenuation by Jupiter-like atmosphere (ammonia) for all planets.


Geometry matters
bits per second
10000
1000
100
10
0
10
20
30
40
Range to Earth
SKA at Zenith (10 bars)
SKA at 45 deg (10 bars)

How to Proceed?

1. "O" on Jupiter: **Juno** sounds deep atmosphere of Jupiter for H20, NH3 and spatial variations.
2. Shallow multiprobes (5-20 bars) using direct-to-Earth communications for Saturn, Uranus and Neptune
   - Intially no H20 (like Galileo)
   - H/He, D/H, 3He/4He
   - Ne, Ar, Kr, Xe, + Isotopes
   - N, S, C

Near Term Probe Missions to Outer Planets

- Flyby with probes
  - Flyby “carrier” has microwave radiometry for global coverage (similar to Juno)
  - Probes use direct-to-Earth communications
  - Possible in Discovery/New Frontiers: i.e. near term
- Orbiter with Probes
  - Higher data rates via “orbiter” link
  - Requires Flagship missions: i.e. distant future